Assessment and Reconstruct of Navy's Mine Impact Burial Prediction Model

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LONG-TERM GOALS

The ultimate goals are to substantially improve, quantitatively, the U.S. Navy's mine burial predictive capabilities and to provide a complete data set of mine movement in water phase and mine impact burial for model evaluation. The goals include development of a new mine impact burial model for improving Naval technical decision aids and involvement of NPS students' (U.S. Naval officers) thesis study for enhancing their combat effectiveness.

OBJECTIVES

The objectives of the project are assessment of current Navy's Impact Burial Prediction Model (IBPM), and reconstruct of IBPM using the advanced hydrodynamic theory. Both efforts are closely connected to the field experiment at Corpus Christi, Texas-Louisiana shelf sponsored by ONR IBPM program.
This effort provides guidance for field experiments such as site selection, determination of variables to be measured (e.g., ocean and sediment conditions as well as mine burial depth). On the other hand, data collected from the field experiments will be used to verify the reconstructed IBPM in a more realistic environmental scenario.

APPROACH

The approach included experimental and modeling tasks and interelated objectives identified in the section above to develop a comprehensive Mine Impact Burial Prediction Model.

(A) Experiments: A series of mine drop experiments with different sizes of model mines were conducted: 1/15th at NPS, 1/3rd at the Naval Surface Warfare Center (Carderock), and full size at Corps Christi, Texas to obtain a complete dataset for depicting the mine movement in the water column:

(A1) Mine Drop Experiment (MIDEX)

MIDEX (1/15th size) took place at the Naval Postgraduate School swimming pool in June 2001. It consisted of dropping cylindrical mine shapes into the water and recording the position as a function of time using two digital cameras at (30 Hz) as the mine shapes fell 2.4 meters to the pool bottom. The scale of the mine used was tailored to be representative of dropping a full-scale bottom mine into 45 meters of water. A 15:1 ratio provides a safety factor on weight so as to not damage the bottom of the pool. There are about 300 mine drops during MIDEX.

(A2) Carderock Mine Drop Experiment

A model mine ($1/3^{rd}$ size) drop experiment was performed at the Naval Surface Warfare Center (Carderock) Carderock in September 2001, led by Dr. Philip Valent at NRL. Concerns over "dynamic similarity" via Reynolds number differences between scaled models and full size prototypes led the Mine Burial Project Team to determine 1/3-rd scale models, with diameter of 0.168 m, length to diameter ratio of 3 and 6, and mass up to 45 kg, were the smallest acceptable model size.

(A3) Corps Christi Mine Drop Experiment

A full size instrumented mine drop experiment was conducted on R/V Gyre, Corps Christi, TX, 5-16 MAY 2002. LCDR Evans from NPS participated the experiment. Due to adverse weather and sea conditions during the subject cruise, we completed only ten instrumented cylinder drops with complete data recovery, and two long-term penetration tests with the inert Mk-52 mines. Two of the instrumented cylinder drops were with the hemi nose, four with the blunt nose, and four with the chamfered nose with chamfer facing up at release.

(B) Observational Data Analysis and Processing: The data collected from mine drop experiments with various sizes were analyzed and processed into the same data format.

(C) Modeling: Most important step toward building a realistic IBPM is to build a 3D hydrodynamic model with full physics including the balance of the moment of momentum. With a non-uniform mass distribution, the gravity center (depending on individual mine) and the buoyancy center (depending mine shape) are not co-located. The new IBPM model should have moment of momentum balance,

$$\int[\mathbf{r} \times (d\mathbf{V}/dt)]\, dm = \mathbf{M}_{w,a} + \mathbf{M}_b + \mathbf{M}_d\,, \qquad (1)$$

Eq(1) should be included into the new hydrodynamic model.

(D) Model-Data Comparison: The existing IBPM model (IMPACT28) and the proposed new 3D model should be evaluated by the observational data collected from the mine drop experiments.

WORK COMPLETED

Data analysis on MIDEX ($1/15^{th}$ size) conducted in June 2001 was completed. The dataset contains around 300 mine drops with different mine parameters (L/D, COM) and drop conditions (angle and velocity). Both dimensional and nondimensional data are available. The data were transferred to the IBPM community such as to Drs. Alan Brandt and Sarah Rennie at the APL Lab in the John Hopkins University.

Two mine drop experiments (led by Dr. Valent at NRL) with $1/3^{rd}$ size at NSWC- Carderock and with full size instrumented mines were completed. Dr. Peter Chu and LCDR Ashley Evans at NPS contributed to the design of the Experiments and LCDR Evans participated the experiments to gather a statistically representative data sample from many test drops of scaled models. LCDR Ashely Evans participated the experiment and started the data analysis.

The mine drops of interest for model validation, 44 drops total from the NSWC-Carderock experiment, consisted of all in water drops of blunt nosed mines from three initial target drop orientations; horizontal, vertical, and $45°$ nose down. Due to the buoyancy moment acting on the mines during initial water insertion the target drop orientations were not achieved for all orientations. The analysis on the data collected from the NSWC-Carderock experiment was completed. The data have the same format as the MIDEX data.

The hydrodynamic system depicting the movement of rigid body (such as mine) in the water column has been established on the base of balance of momentum and moment of momentum. This system consists of nine nonlinear equations. Among them, three equations depict the acceleration of the center of mass; three equations depict the moment of momentum balance, and three equations predict the three Euler angles of the mine. This hydrodynamic system does not have analytical solutions due to the nonlinearity. We are developing a ***matrix transform method*** to solve the problem.

IMPACT28 was evaluated using the observational data collected from the two mine drop experiments: MIDEX (1/15th size) and NSWC-Carderock (1/3rd size).

RESULTS

(1) After analyzing the MIDEX (1/15th size) and NSWC-Carderock (1/3rd size) data, the same trajectory patterns were observed (Figure 1 and Table 1).

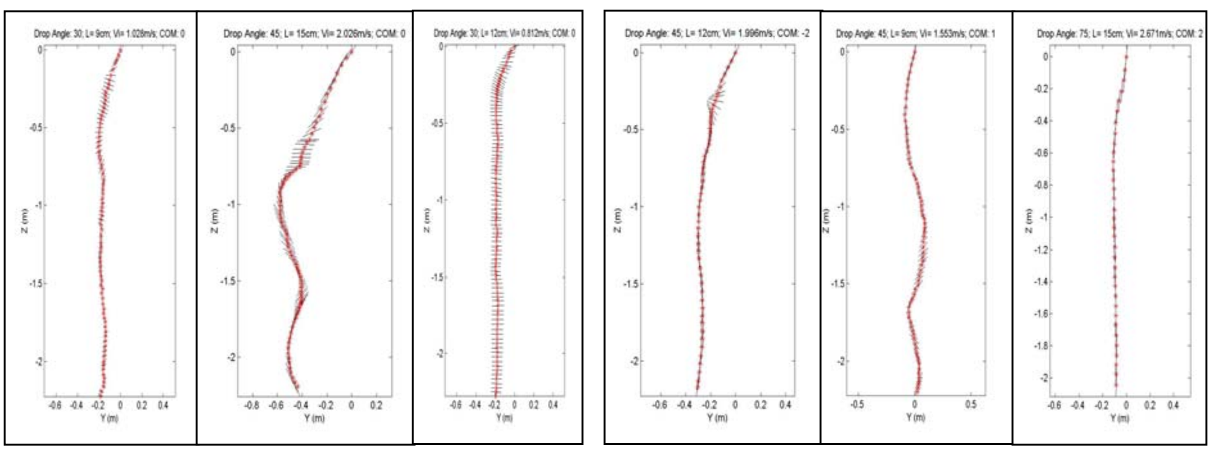

Figure 1. Trajectory patterns observed in both MIDEX (1/15th size) and NSWC-Carderock (1/3rd size) Experiment.

(2) Programs were developed for quality control and data conversion among mine drop experiments with various mine scales. A unified dataset (mine velocity and orientation) has been established for 3-D model development and verification.

Table 1. Description of Mine Trajectories in MIDEX and NSWC-Carderock Experiment

Mine Trajectory Pattern	Description
Vertical	Mine exhibited little angular change about z-axis.
Spiral	Mine experienced rotation about z-axis.
Flip	Initial water entry point rotated at least 180° during mine motion.
Flat	Mine's angle with vertical near 90° for most of the trajectory.
Seesaw	Similar to the flat pattern except that mine's angle with vertical would oscillate between greater (less) than 90° and less (greater) than 90° - like a seesaw.
Combination	Complex trajectory where mine exhibited several of the above patterns.

(3) A new 3-D hydrodynamic model for predicting mine velocity and orientation in the water phase was developed.

(4) Preliminary evaluation on the 3D hydrodynamic model was conducted using the MIDEX data. In the evaluation, the 3D model was integrated for various initial conditions and mine parameters such as L/D and distance between centers of mass and volume used in MIDEX. The 3-D model has capability to predict the mine movement in the water column.

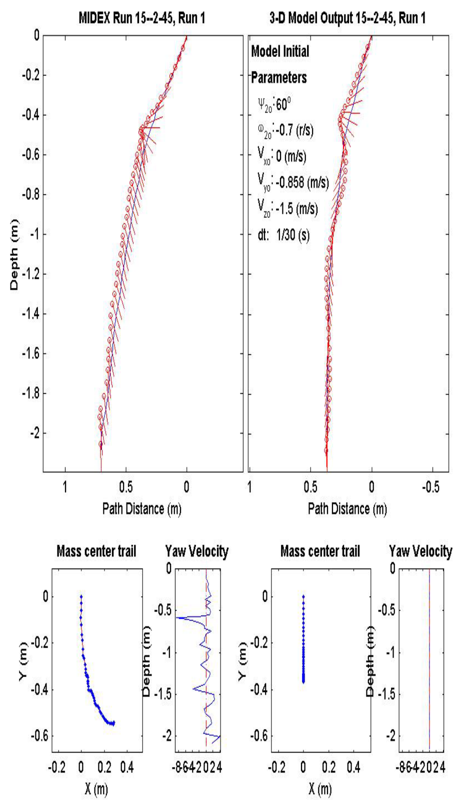

Figure 2. 3-D model generated and observed mine trajectories.

(5) IMPACT28 was carefully evaluated using the MIDEX and Carderock experiment data. IMPACT28 was integrated with mine parameters and initial drop conditions same as each drop in the two experiments: MIDEX and Carderock experiment. Two major results were obtained: (a) IMPACT28 overpredicts the impact velocity at the bottom sediment (Figure 3); (b) IMPACT28 has no capability to predict the impact angle (Figure 4).

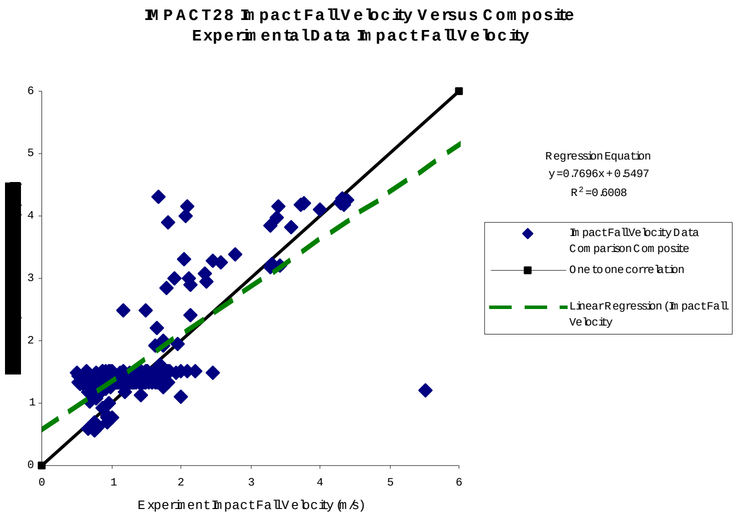

Figure 3. Comparison between IPACT28 predicted and observed mine impact velocity (vertical velocity) on the bottom. The model overpredicts the impact velocity.

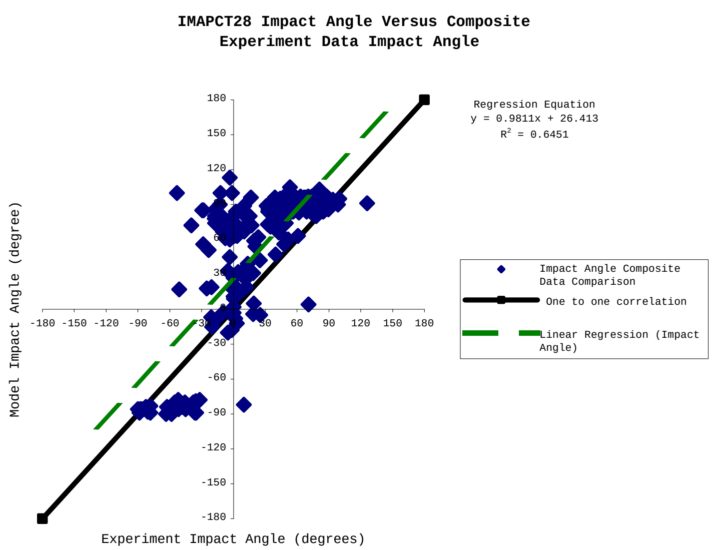

Figure 4. Comparison between IPACT28 predicted and observed mine orientation on the bottom. The model has no capability to predict the mine orientation at the bottom.

IMPACT/APPLICATIONS

• The dynamic system (nine nonlinear equations) for the mine movement has the potential impact on the nonlinear dynamics. The hydrodynamics of mine impact in water column can be applied to a general scientific problem of the fluid-rigid body interaction including stability and chaotic motion.
• The datasets obtained from three consecutive experiments, MIDEX (1/15th scale), NSWC-Carderock (1/3rd scale), and Corps Christi experiment (full scale) will impact the scientific and Naval mine warfare communities on the mine movement in the water column.

TRANSITIONS

• The results obtained from this project are transferred to the Naval Oceanographic Office, COMINEWARCOM, and the ONR Mine Impact Burial Prediction group such as the mine expert system and mine scour and liquifaction groups.
• Two major results of IMPACT28 (over predicting the impact velocity and no capability for predicting the mine orientation) were obtained. The weakness is caused by incorrect physics (tumbling of mine and no moment of momentum balance) that are well accepted by the mine warfare community.
• The datasets collected from MIDEX (1/15th size), NSWC-Carderock Experiment (1/3rd size), and Corps Christi Experiment (full size) will greatly impact on the development of an accurate Mine Impact Burial Prediction Model.
• The data were also used for development of the Expert System for Mine Impact Burial at the Applied Physics Laboratory of the John Hopkins University and the Environmental Sciences Department of the University of Virginia.
• The data were also used for development of the Mine Scouring and Liquifaction modeling effort at the Scripps Oceanographic Institution (headed by Dr. Scot Jenkins).

RELATED PROJECTS

This project is related to the ONR Expert System program. The results obtained from this project are the basic materials for building the Expert System for mine burial prediction.

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PATENTS

None